THE TECTONICS OF THE CENOZOIC VOLCANISM IN HUNGARY

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SUMMARY

The interrelation of volcanic and tectonic phases in the Neozoic of the Hungarian part of the Carpathian Basin was studied. It is found that the phases of volcanic activity coincide with phases of crustal distension, indicated by normal faulting, while the phases of compression bring about the closure of the magma channels beside forming reverse-faulted and sometimes slightly folded tectonics. The tectonic stresses and strains have, besides acting as a regulating valve of volcanism, also contributed to the activation of the magma. The thinness of the Hungarian part of the crust is presumably due to the effect of Neozoic volcanism. The heat residue of magmatic activity may be responsible for the high heat flow values in present-day Hungary.

Introduction

Magmatic petrology has one common feature with electronics. Electronics is an exact an exceedingly efficient discipline which was established without knowing exactly what an electron is. Magmatic geology is likewise an edifice of well-systematized knowledge which has been erected without exactly knowing where the magma comes from and what makes it surge. In the following an attempt will be made to explain the origin of magma in a limited space and time, namely in the Cenozoic of the Carpathian Basin. The evidence used will be derived from results of research on crustal structure and crustal development.

Preliminary remarks

The basic statements which will be used as starting points are as follows.

1. It is a geophysical commonplace that no contiguous magma belt can exist below the surface of the Earth in a depth which is reasonably small so as to permit the surge of magma up to the surface. This fact is accepted, if somewhat reluctantly, by most petrologists of our day. At present, the problem is the mode of origin and the depth of the local magma chambers which are active for certain periods beneath certain parts of the terrestrial crust.

2. The Hungarian part of the crust, although it occurs in the embrace of intensely faulted orogenies, was not compressed in the course of all of its history. On the contrary, in some instances it was subjected to tensile stresses resulting in distension up to 3 per cent. This was shown by the author through the analysis of geological profiles (1). These distensions could have resulted from an over-all expansion of the Earth (2) on the one side, and from

the relaxation of the crust after its release from orogenic compression on the other. From the point of view of our present problem this uncertainty is of no importance, however.

3. The Hungarian part of the Earth's crust is at present one of the thinnest in all Europe, with an average thickness around 24 kilometres, i.e. some 6 kilometres smaller than the European average, as was shown by seismic experiments by G á l f i and S t e g e n a (3). This is peculiar inasmuch as in the Mesozoic this part of the crust has been more rigid than any of the surrounding parts, having been characterized by epicontinental sedimentation rates as contrary to the geosynclinal ones all around and by small-scale Saxonotype tectonics as contrary to the large-scale folding and napping in the surrounding orogenies. Therefore, the crust of the Mesozoic must have been a thick and rigid one. The reason of its thinning to its present dimensions was by the author considered to have been Tertiary volcanism (4).

4. According to the geothermal investigations of B o l d i z s á r the terrestrial heat flow in Hungary is about twice the world average and "the reason (for that) has up till now not been explained" (5).

It will be attempted in the following to draw such a coherent picture of the interrelations of magmatic and tectonic activity into which all the above-mentioned observations may be fitted and which is able to explain the problems raised above.

Interrelations of magmatic and tectonic activity

In the Hungarian Cenozoic, the following phases of tectonic movement were detected: 1. the *Laramian* phase, at the boundary of the Cretaceous and Eocene; the *Pyrenean*, some time before and at the upper boundary of the Eocene; 3. the *Savian*, at the boundary of Oligocene and Eocene; 4. the *Styrian*, at the boundary of the Helvetian and Tortonian stages of the Miocene. From this time on the picture becomes somewhat more complicated, as because of the greater resolving power of geological insight we are able to determine a great many small phases, up to the Holocene. Of these, some are very intense as related to the others, and these will be summarized under the name "*Pannonian movements*", coinciding about with Stilles's Attican and Rhodanian phases. The above-named phases were all characterized by faulting and sometimes by slight folding. A number of other phases are demonstrated by unconformities. These will be left out of consideration here.

Let us consider these phases one by one.

1. The Laramian phase succeeds the very intense Mesozoic Austrian diastrophism, therefore it is difficult to distinguish. In localities where there are upper Cretaceous strata, covered by Eocene, the effects of the Laramian phase may be studied by considering those movements which have acted upon the upper Cretaceous but not on the Eocene. Such localities are the Ajka environment and part of the Bakony Mountains around Pápa. Around Ajka, the Laramian is found to have caused some normal faulting (6) resulting in distension of up to 4 per cent. There is no reason why a different type or intensity of movement should have prevailed in any other part of the country. No magmatic accompaniment to the Laramian phase is known, so that there is no evidence as to the existence of a magma chamber at this time.

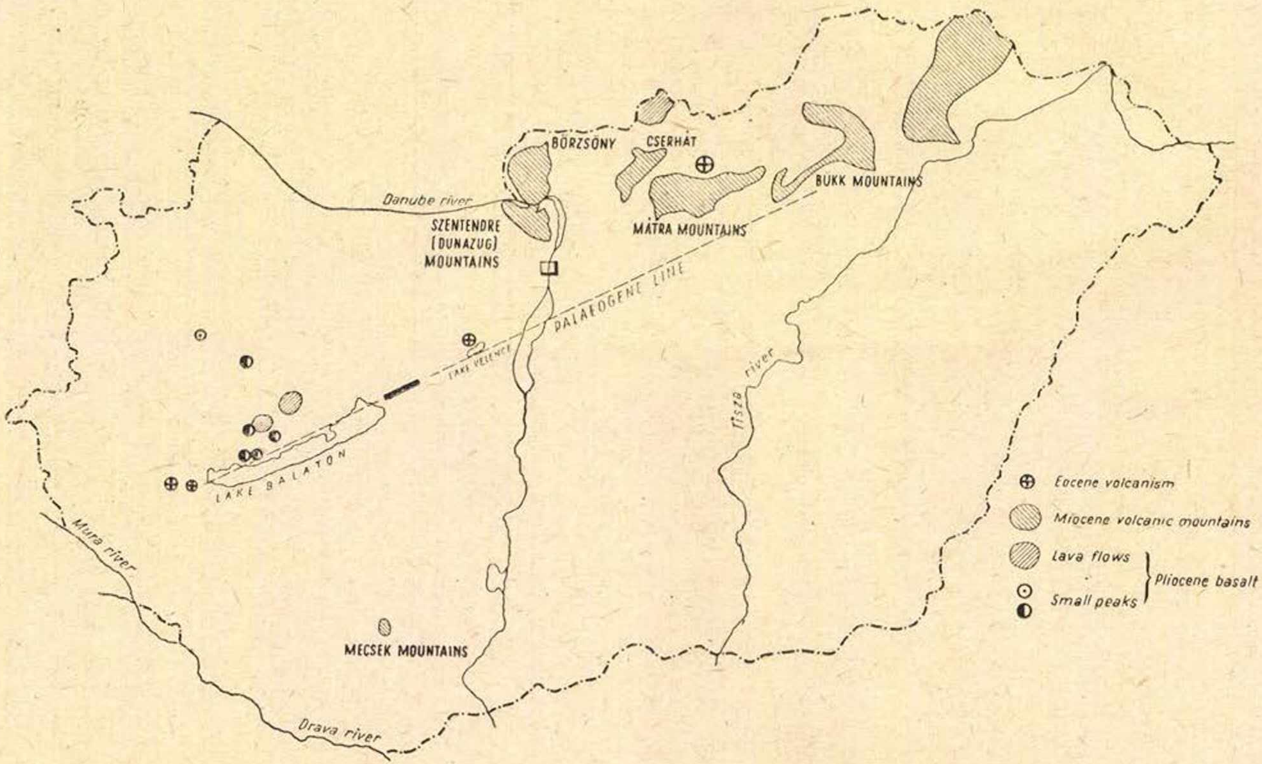

Fig. 1. Map of Hungary, indicating the names of the mountains, the Palaeogene line, and the volcanic formations of the Cenozoic

2. In his lucid treatment of the Hungarian Palaeogene formation, Szőts (7) clearly points out the simultaneity of tectonic and magmatic activity, stating that the beginning of the andesite volcanism in the Velence Mountains coincides with a precursory phase of the Pyrenean, while in the main Pyrenean phase both the Velence Mountain volcano and another in the environment Mátra Mountains have burst into activity. As far as there exist reliable geological profiles illustrating these movements, they show them to have been tensile in nature, resulting in normal faulting (8). Volcanic activity is situated along two points of a line of great importance in Hungarian palaeogeography, called the Palaeogene line, running along the Southern shore of Lake Balaton parallel in strike to the Hungarian Mountains and delimiting the Palaeogene formations toward the south. Evidently this is an axis of crustal bending, along which the down-buckling of the crust resulting in the Palaeogene sedimentary basin north of this line came about. These traces of volcanism are to be regarded as the first manifestation of a deep fault leading to a magma chamber.

3. The magmatic activity which commenced in the Pyrenean kept on throughout the Lattorfian and Rupelian stages of the Oligocene, yielding a great amount of tuffs interbedded with marine sediments of this period. In the Chattian, a reluctant closing of the magma channels is observed, forecasting the shadow of the Savian phase. The eruption centres were closed down or have shifted into unknown distances.

4. The Savian phase brought intense compression resulting in the folding of the Flysch series below the Great Hungarian Plain against the crystalline spur reaching east from the Transylvanian Mountains. On the surface, this is indicated by the overthrusts of the so-called Darnó Line system, delimiting in part the Meso-Palaeozoic bulk of the Bükk, Uppony and Rudabánya mountains against the surrounding Tertiary sediments. The movement manifested itself also in some bending of the Oligocene sediments. No volcanic activity is known around this time, from the Chattian to the formation of the allegedly Burdigalian, so-called Lower Rhyolite Tuff. Crustal compression has strangled volcanic activity.

5. In the Styrian phase, volcanic activity shows a quite sudden recovery with eruptions on a large scale in the Dunazug, Börzsöny, Cserhát and Mátra Mountains, in the Mecsek Mountains and presumably also below the Little Hungarian Plain (according to geomagnetic evidence and deep-borings). Some precursory eruptions may be supposed in the area around the Tokaj Mountains and in the "fire belt" parallel to the Northeastern and Eastern Carpathians. This large-scale volcanic activity is accompanied by similarly large-scale normal faulting.

In the environment of the most intense volcanism of this time, in the Börzsöny—Cserhát—Mátra Mountains area, in the Borsod and Salgótarján coal measures, thoroughly mapped normal fault systems show amounts of distension of two to ten per cent. In the Cserhát Mountains the volcanic superstructure is eroded: the substructure reveals itself to consist of a dike swarm, the orientation pattern of which is shown as Fig 2. The small maximum at about 150° strike is due to a deflection of the northernmost part of some of the dikes. These deflections all occur along a line of east-west strike (Fig. 3). As north of this line all evidence points to the basement being crystalline, while south of it some scarce data show it to be Mesozoic, the deflection seems to indicate a difference in the strength of the basement rocks. The fault pattern of the area, in a sense complementary to the dike system, is also shown in Fig. 2. The dikes and faults form a system of Mohr planes indicating either meridional distension or east-to-west compression. The fact that the magma was able to rise through the fractures, forming dikes of a width reaching hundred metres, shows that the first possibility was realized. — The small volcanic mass in the Mecsek Mountains is connected, although perhaps not exactly simultaneous, with a phase of normal faulting (9).

6. In the Sarmatian stage of the Miocene the volcanic activity shows a west-to-east shifting. In the area west of the Bükk Montains Miocene volcanism ceased in the Tortonian or around the beginning of the Sarmatian. In the Tokaj Mountains and in East Slovakia it reached its paroxysm just at this time and it ended only some time in the Pannonian, presumably on the boundary of its lower and upper division. In Transylvania it went on up to and into the Pleistocene. This shifting is due to a scissors-like closure of the volcanic channels, proceeding west to east. The reason for this closure was a phase of compression which was called Pannonian a-

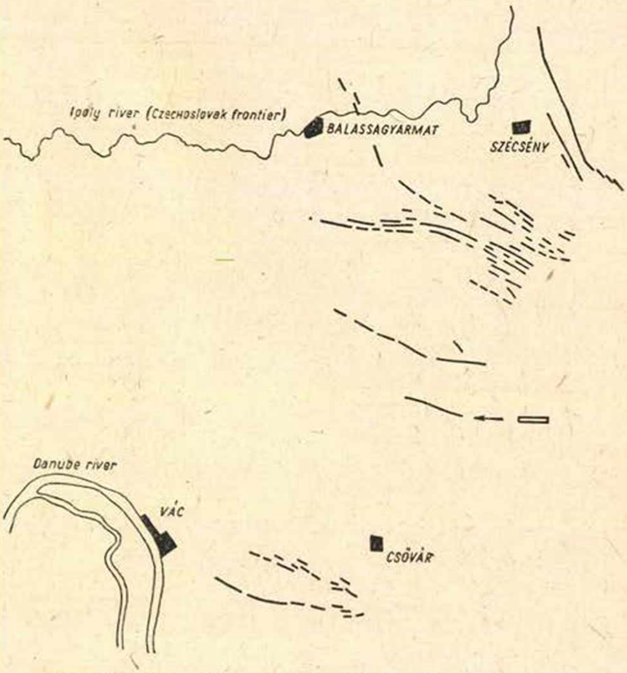

Fig. 2. Map of the Cserhát Mountains dike swarm

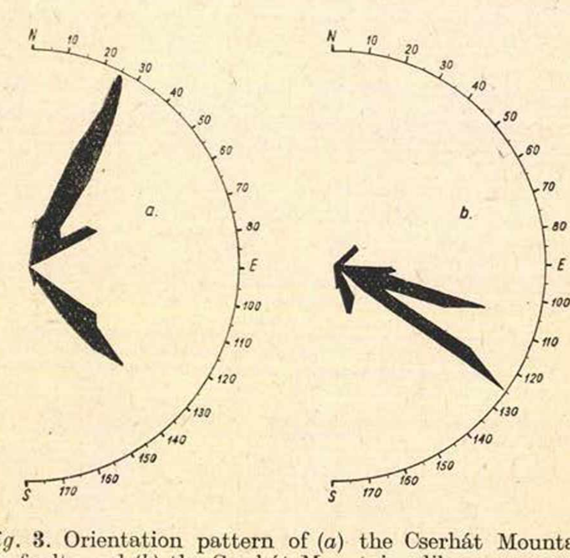

Fig. 3. Orientation pattern of (*a*) the Cserhát Mountains faults and (*b*) the Cserhát Mountains dike swarm, bove. This was intense in the west and weak in the east. In the west it has brought about the formation of the so-called Save folds between the Save and Drava rivers, and the highly complicated folding and overthrusting of parts of the Mecsek Mountains. It was also felt and demonstrated in the Bakony Mountains (10). In the east it is hardly demonstrable if at all. The moving of the Mesozoic over supposedly Burdigalian clays as a rejuvenation of the Darnó Line overthrusts (11) and an ill-disclosed folding of the post-volcanic Pannonian in the Tokaj Mountains (12) are the none too reliable evidence for this phase in the eastern area. The fact that volcanism kept on unhampered in Transylvania may be due partly to the lack of compression and partly to the fact that the strike of the volcanic chain there is almost perpendicular to the direction of compression. Anyhow, volcanism has not ceased there.

7. While the andesitic volcanism of Pacific type, characteristic of the Miocene, kept on in Tranyslvania, a different sort of magma has risen in the Bakony Mountains and in the Little Hungarian Plain and in Nógrád, respectively. These basalts are coeval with the development of some of the marginal normal faults of our mountains, with throws of one thousand metres in some instances. The chemical composition of the basalts is alkaline, Atlantic. This difference in chemical composition points to a difference in origin, presumably due to the opening of a set of new deep faults and to the formation of a new magma chamber.

Conclusions

1. From the above said it emerges clearly that the tectonical movements play the part of a regulating valve of magmatic activity. Phases of tension are favorable to volcanism, while phases of compression act as inhibitors. There is, however, a phase shift between volcanic and tectonic paroxysm. After the magmatic channels have been opened by tension, volcanism goes on for a while, up to the time when compression builds up a sufficient strain to lock the magma in. However, in the sediments the compression will cause deformation only some time after the volcanism has been stopped. This relationship was already pointed out by V a d á s z (13), in his grand synthesis of Hungarian magmatic activity.

The crustal deformations attested by surface tectonics have necessarily liberated great amounts of heat of deformation. As was demonstrated by the detailed computations of C o n t i n i (14), this heat is quite sufficient to activate the magma, i. e. to bring about the formation of a magma chamber. Although the appearance of the magma on the surface is connected with phases of distension, its formation is the joint work of distensive and compressive phases and even of epeirogenic bending, so frequent in the Hungarian Tertiary. Therefore, not only the regulation but also the formation of the magma chamber is assumed to be the result of local tectonics.

The magma activated by the phases of distension was not necessarily solidified by subsequent compression. The sudden jumping into life of volcanism over a very large area in the Styrian, after the Savian compression, seems to be in favour of this assumption.

The thinning and weakening of the crust is, when considering sedimentation rates, subsequent to the intense phases of volcanism. As was shown in an earlier paper (4), sedimentation rates in the Carpathian basin were for the first time equalling those of the Alps in the Oligocene, i. e. at the time of the copious Lattorfian to Rupelian volcanism, resulting in the area north of the Palaeogene line in an Oligocene series of up to 2000 metres. It was in the Pannonian that the sedimentation rate in the Carpathian basin exceeded that of the Alps for the first time, due to a sinking which commenced in the Tortonian. This sinking has resulted in sedimentary series up to 4000 metres. The sinking due to volcanism is partly a result of the volcanic overburden, partly of the melting of the substratum and partly of the thinning of the crust. The fact that the magma chamber was in the immediate neighbourhood of the lower crustal boundary (the Mohorovičić surface of geophysicists), is proved by that 1. the composition of the pre-Pliocene volcanism is rather acid, dacito-andesitic on the average, 2. pre-Pliocene volcanism has a very great extension all over the country, suggesting a shallow magma pool. The Pliocene basalts are a different matter. Their composition indicates them to be of deeper origin. They are accompanied by no sinking, either.

Volcanic activity must have been accompanied by magmatic currents of some extent. The term is not understood here in Griggs's sense. The magmatic currents I refer to are thought to be quite shallow and of small depth. Such a magmatic displacement could have brought about the shifting of the magmatic activity after the Styrian, as described above. Stille (15) also considered that the magma or at least the raw material of the same was shifted from below the Carpathian orogenies, where it could not break up, towards the basin center.

The circumstance that e. g. the Styrian phase has brought about dis tension in the Basin, while all around, it is considered to have been compressive-giving rise to folding and even napping in the Alps and Carpathians, shows. that areas as small as the Carpathian Basin can have their own tectonic regime, which is overwhelmed only by the most intense paroxysms of mountain building of the surroundings.

Because of the poor heat conductivity of the crust and because the movements continued even in the Pleistocene (16), the cooling subsequent to the emptying or resolidifying of the magma chamber must have been very slow. This may be the explanation of the geothermal observations of Boldizsár. Thus, the Basin seems to have besides an independent tectonic regime a similarly independent heat household, too.

It must be pointed out that the utmost care has to be exercised attempting to extend the above-outlined ideas to other parts of the world. Such an extension will necessitate thorough studies of comparative magma tectonics.

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